E7.6-10257
CR-146629

APPLICATION OF LANDSAT DATA TO DELIMITATION OF AVALANCHE HAZARDS IN MONTANE COLORADO

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(E76-10257) APPLICATION OF LANDSAT DATA TO DELIMITATION OF AVALANCHE HAZARDS IN MONTANE, COLORADO Interim Report, Dec. 1975 - Feb. 1976 (Colorado Univ.) 16 p HC $3.50 CSCL 08L G3/43

N76-21630

Unclas 00257

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R. Summer

March 1976

Interim Report for Period December 1975-February 1976

Third Quarterly Progress Report

Prepared for:

Goddard Space Flight Center

Greenbelt, Maryland 20771

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Application of LANDSAT Data to Delimitation of Avalanche Hazards in Montane Colorado		5. Report Date March, 1976 6. Performing Organization Code
7. Author(s) D. H. Knepper		8. Performing Organization Report No.
9. Performing Organization Name and Address Institute of Arctic and Alpine Research University of Colorado Boulder, Colorado 80309		10. Work Unit No. 11. Contract or Grant No. NAS 5-20914
12. Sponsoring Agency Name and Address NASA Goddard Space Flight Center Greenbelt, Maryland 20771		13. Type of Report and Period Covered Type II Progress Report: 12/75-2/76 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Areas of active avalanching are difficult or impossible to identify with certainty on the LANDSAT imagery of Colorado that has been studied. The major difficulty is that the direct indicators of avalanching are too small to be resolved by the LANDSAT system and/or physically similar to non-avalanche features common in the area. This problem, and the problem of the lack of stereoscopic coverage, can be overcome by interpreting indirect avalanche indicators and using small-scale topographic maps as a guide to interpretation.

17. Key Words (Selected by Author(s)) avalanche, LANDSAT, Colorado	18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
unclassified	unclassified	16	

*For sale by the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151.

PREFACE

Over the last several years, the Institute of Arctic and Alpine Research (INSTAAR) at the University of Colorado has been involved in the delineation, mapping, and analysis of natural hazards in selected portions of the Colorado Rocky Mountains. Much of this research has been concerned with the detailed delineation of snow avalanche hazards using air photo and field mapping techniques. Continuous monitoring of various environmental parameters during the winter avalanche cycle has produced significant advances in the field of avalanche prediction and forecasting for local areas.

In June 1975, INSTAAR began research for the National Aeronautics and Space Administration (NASA contract NAS5-20914) on a new approach to avalanche hazard investigation. The purpose of this research is to analyze, evaluate, and apply LANDSAT imagery for delineating and mapping avalanche hazards in the Colorado mountains. Research is currently being directed toward six primary objectives:

(1) Compilation and analysis of historical avalanche records for cause/effect and frequency information.

(2) Identification of avalanche hazard terrain characteristics detectable on LANDSAT imagery.

(3) Determination of relative usefulness of LANDSAT imagery for avalanche hazard mapping.

(4) Determination of useful schemes for cartographically representing avalanche hazards.

(5) Using the synoptic and repetative aspects of LANDSAT imagery for regional avalanche hazard mapping and analysis.

(6) Examining the cost/benefits of avalanche hazard investigations.

Secondary, and purely experimental, objectives of the research project are as follows:

(1) Investigation of potential usefulness of LANDSAT derived information as input to avalanche forecast or warning systems.

(2) Investigation of the usefulness of LANDSAT imagery for mapping major landslide areas.

During the report period (1 December 1975 - 29 February 1976), research was conducted by two INSTAAR research staff members, one full-time and one part-time. Two full-time researchers will be working on the project during the next report period. During this report period, studies have shown that:

(1) With rare exceptions, avalanche areas cannot be uniquely identified on LANDSAT imagery. Interpretations of the imagery based on other than direct evidence does, however, allow a reasonable approximation of the distribution of avalanches to be made.

(2) Frequent reference to small-scale topographic maps during LANDSAT imagery interpretation allows good interpretations to be made in areas where stereo is not available.

(3) Avalanche hazard mapping on a regional scale is best conducted using LANDSAT imagery in conjunction with supplementary data sources. The level of detail attained by this mapping will be limited by the amount of supplementary data used and the scale of the final map.

CONTENTS

	page
INTRODUCTION	1
IDENTIFICATION CRITERIA	2
AVALANCHE HAZARD MAPPABILITY	5
REGIONAL AVALANCHE MAPPING	9
SIGNIFICANT RESULTS	10
PUBLICATIONS	11
RECOMMENDATIONS	11
FUNDS EXPENDED	11
REFERENCES	11

INTRODUCTION

This report summarizes the work conducted by the Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, during the period 1 December 1975 - 29 February 1976, under contract NAS5-20914 to the National Aeronautics and Space Administration/Goddard Space Flight Center.

During the report period, it was concluded that avalanche hazard areas cannot be uniquely identified on LANDSAT imagery, except in rare instances. Consequently, a methodology for using supplementary information in conjunction with the LANDSAT imagery was developed and the new method was used for avalanche hazard mapping in the Durango and Montrose quadrangles (1:250,000). The new method involves distinguishing three levels of avalanche hazard based on LANDSAT imagery interpretations, topographic map analysis, and identification of known avalanche areas: (1) potential -- from elevation and relief considerations; (2) interpreted -- from LANDSAT imagery in conjunction with small-scale topographic maps; and (3) identified -- from historical documentation and field and air photo inspection.

IDENTIFICATION CRITERIA

Research conducted during the previous report period (1) indicated that direct indicators of avalanche activity, including vegetation and snow distribution patterns, could not be consistently interpreted from single-band, black and white positive transparencies of LANDSAT imagery of the San Juan Mountains. Further studies during this report period have substantiated this conclusion, and we now feel that, with rare exceptions, avalanche areas cannot be uniquely identified on available LANDSAT imagery even when using stereoscopic analysis techniques.

This statement is based on the premise that in order to identify avalanche areas, it must be possible to identify evidence that is the direct result of avalanche activity (direct indicators). In the general case, these direct indicators have proved extremely difficult to detect, and nearly impossible to identify, on the LANDSAT imagery of southwestern Colorado. The difficulty stems from two considerations. First, the direct indicators of avalanche activity that are so apparent on air photos and in the field are, for the most part, too small to be adequately resolved on LANDSAT imagery. In our studies of LANDSAT imagery of known avalanche areas, where direct indicators are well-developed and relatively large, we have been able to detect the presence of these indicators, but the depiction of these features on the imagery is too vague for positive identification to be made. Therefore, the best we can do is to interpret them and attempt to substantiate the interpretation by other methods.

Second, the appearance of common avalanche indicators on the LANDSAT imagery is often similar to common non-avalanche features. For example, trimlines are easily confused with (1) timber line, (2) tree line between

slopes and adjacent valley bottoms, and (3) shadow/non-shadow boundaries. Each has similar geometry and (1) and (2) above and trimlines are physically and, consequently, spectrally similar.

It may be possible to improve the identification, or tentative identification, of avalanche hazard indicators by enhancing the LANDSAT imagery. The INSTAAR Spatial Data Systems Model 703, after long delay, has finally been repaired and will be used during the next report period. An alternative, digital processing, was discussed with the U.S. Geological Survey, Denver, but limitations on their time are such that it is doubtful whether they will be able to prepare any digitally-enhanced imagery for us. In addition, further study of the size of the direct avalanche indicators that we would be trying to identify indicates that, by and large, these features are too small to be resolved by the LANDSAT system, so it is doubtful whether any kind of enhancement will significantly improve the ability to identify these features on the imagery.

Since the identification of avalanche areas on LANDSAT imagery is so rare in comparison to the actual number of avalanche areas present, a regional delineation of avalanche hazards based only on LANDSAT imagery analysis does not appear to be viable; such a map would be truly misrepresentative of the actual distribution of avalanche areas. The question is, then, how much can we rely on "interpretative" evidence and still produce a reasonably accurate map considering the scope of this investigation?

As previously reported, the interpretation of <u>indirect</u> indicators of avalanches does give a reasonable depiction of the distribution of avalanches in the known areas where we have used this method; it is fair to say that rarely have areas subject to avalanching been incorrectly interpreted as avalanche-free. However, the relatively low level of detail

that can be attained and the cumulatively large area that is interpreted as avalanche terrain when it is not, are drawbacks that cannot be ignored even in small-scale, regional avalanche hazard mapping. This situation can be significantly improved by using supplemental data in addition to the LANDSAT imagery as discussed below.

AVALANCHE HAZARD MAPPABILITY

Thus far we have determined that the regional mapping of avalanche hazards cannot be done in enough detail using LANDSAT imagery alone. However, the interpretation of LANDSAT imagery, integrated with readily-obtained supplementary information, should provide a much sounder base for regional avalanche hazard mapping. During this report period, we have developed a procedure for using selected supplementary information in conjunction with LANDSAT imagery interpretations and have begun to routinely apply the technique to regional avalanche hazard mapping in the Colorado mountains. The procedure consists of three steps that overlap and reinforce each other: (1) gross delineation of <u>potential</u> avalanche terrain; (2) <u>interpretation</u> of avalanche terrain; and (3) <u>identification</u> of avalanche terrain.

Potential Avalanche Terrain

Potential avalanche terrain is defined as terrain that has a topographic configuration that will promote avalanching when suitable meteorological and vegetation conditions are established. The variables, mainly the amount of precipitation as snow, temperature and temperature variations, and wind velocity and direction (meteorological) and the presence or absence of mature forest (vegetation), can be approximated regionally by considering elevation above sea level. However, it should be noted that natural and man-induced events may significantly alter the "normal" environment of an area from time to time. The delineation of potential avalanche terrain, then, consists of (1) defining those areas, which by virtue of their elevation, most probably have suitable meteorological and

vegetation characteristics for the development of avalanches and (2) restricting the areas defined in (1) to only those areas that have a suitable topographic configuration (i.e., relief or slope) for avalanches to run. This type of mapping can be conducted by analyzing topographic maps; the detail and accuracy attained is a function of the scale of the topographic maps.

Based on the work by Frutiger (2, Figure 1) and detailed avalanche hazard mapping by INSTAAR personnel (NASA Grant 06-003-200) in the Colorado mountains, the number of avalanches that occur is sensitive to elevation. Avalanches are uncommon below 9,000 feet; between 9,000 feet and 10,000 feet, the number of avalanche occurrences becomes significant. Most avalanches, however, take place between 10,000 feet and approximately 12,000 feet. Above 12,600 feet, avalanches are much less common because these areas are above timberline and are steep and exposed to high winds that tend to restrict the accumulation of snow. These elevation boundaries can be easily traced on topographic maps, producing a map showing the relative <u>potential</u> for avalanches over a large region.

This type of map can, however, be made much more accurate by eliminating those areas above 9,000 feet that do not have the topographic relief necessary to sustain avalanching (mesas, ridge crests, valley bottoms, etc). Because most avalanches in the Colorado mountains occur on slopes between 22^{o} and 45^{o} (2), it would be extremely useful if areas within this range of slope steepness could be delimited. It may be possible to obtain this information using the digital topographic data from the 1:250,000 scale topographic maps of montane Colorado available from the Defense Mapping Service (DMS). Discussions are currently in progress with the U.S. Forest Service on the possibility and practicality of using this data source.

The alternative is to delineate areas with these slope steepnesses manually on the 1:250,000 scale topographic quadrangles. If this method is used, it will not be possible to separate slopes above 45^{o} because contour packing is too close to accurately measure, so only those areas with slopes greater than 22^{o} will be delimited. To complete the task in a reasonable time, the mapping will be done by visual inspection, rather than by rigorous, point-by-point computations.

Interpreted Avalanche Terrain

Interpreted avalanche terrain is terrain that, from interpretation of LANDSAT imagery, appears to actually undergo avalanche activity. This level of mapping will involve the interpretation of indirect (and direct where possible) avalanche hazard indicators from LANDSAT imagery, combined with frequent reference to the small-scale topographic maps and the potential avalanche hazard maps. The conjunctive use of these maps will allow good interpretations to be made in areas where stereoscopic LANDSAT coverage is not available and will preclude the interpretation of avalanche hazards in areas where environmental conditions are most probably not conducive to avalanching.

Identified Avalanche Terrain

The final, and most specific, level of avalanche hazard mapping is the delineation of known avalanche areas. This information will be mostly obtained from existing detailed avalanche hazard maps, supplemented by air photo and field reconnaissance as time permits. Comparison of the known avalanche areas with the interpreted avalanche terrain will serve as a measure of the utility of LANDSAT imagery interpretations for avalanche

hazard mapping. The final version of the avalanche hazard map will show each of the three levels of mapping on a common ba·e map.

REGIONAL AVALANCHE MAPPING

During the report period, preparation of avalanche hazard maps as outlined in the previous section was initiated for the Durango and Montrose quadrangles (1:250,000). These maps are currently in progress and should be completed shortly. Mapping will then be extended to the remaining quadrangles during the next report period. It is anticipated that these quadrangles will be finished by late May or early June. The preliminary maps will then be field and photo checked. Of necessity, field checking will not be detailed and emphasis will be placed on identifying areas of known avalanching that were initially interpreted as avalanches during LANDSAT imagery and topographic map analysis.

SIGNIFICANT RESULTS

1. With rare exceptions, avalanche areas cannot be uniquely identified on LANDSAT imagery.
2. Reference to small-scale topographic maps during LANDSAT imagery interpretation allows reasonable interpretations to be made in areas for which stereoscopic LANDSAT coverage does not exit.
3. Avalanche hazard mapping on a regional scale is best conducted using LANDSAT imagerv in conjunction with complementary data sources. The level of detail of such maps will be limited by the amount and completeness of the complementary information used.

PUBLICATIONS

No project-funded publications were prepared during the report period.

RECOMMENDATIONS

No specific recommendations are necessary at this time.

FUNDS EXPENDED

A total of $23,776 has been spent on the project.

REFERENCES

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2. Hans Frutiger. Snow Avalanches Along Colorado Mountain Highways: U.S. Forest Service Research Paper RM-7, 1964, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.